Project 06 - Group 3:
Behavior of a Shear Thickening Fluid

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Abstract: Non-Newtonian fluids are fluids which experience a change in viscosity under different shear strain rates. These fluids may be shear thinning where viscosity decreases with an increase in shear, or shear thickening where an increase in shear rate results in a greater apparent viscosity. This image is an example of the later; a fluid in which a greater shear strain rate causes the fluid to resist flow exponentially. Under great enough stresses, these fluids reach a point in which they act similar to a solid and can even fracture. The following is an investigation of this mechanism.

Non-Newtonian fluids are fluids in which the apparent viscosity of the fluid changes with a changing rate of strain (see Figure 1 :). That is, a change in momentum in a flow does not have a linear relationship to the resistance of the fluid flow. In this third group project, the purpose of the experiment is to photograph a fluid which has an increasing apparent viscosity (resistance to flow) in response to an increase in the shear rate, or a shear thickening fluid.[1] In the context of the image, the shear thickening event is most visible near the interface between the falling, stream of fluid and a hard surface. This creates a sudden change in velocity and thus an applied shear to the flow which is resisted. Near this boundary, the liquid maintains a more solid shape, while everywhere else the flow more closely resembles the structure of a common liquid.

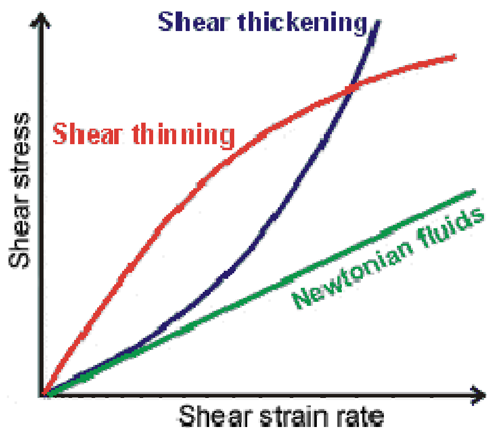

Figure 1 : Shear strain rate vs. Shear stress for Newtonian and non-Newtonian fluids.

To create the flow in the image, a mixture of cornstarch and water was used to produce a shear thickening fluid. The appropriate solution creates a fluid that may be rolled into a ball, but liquefies once applied forces stop. The photographed flow is a cornstarch/water mixture that has been rolled into a ball and then squeezed by hand. The result is streams of fluid flowing from the cracks between my fingers that falls about 6 inches to a table (streams are approximately 4 inches high in the image – see Figure 2: **Schematic of the photographic set up.**). As this flow hits a counter top, the sudden change in momentum causes an applied shear strain which the fluid resists and thus maintains its previous shape longer. Shortly after, the fluid experiences a particle relaxation response which allows the particles to flow more freely and a small reservoir forms on the counter top. The velocity of the falling fluid is approximately 8 in/s. The associated Reynolds number for this flow is of order 10[1], which is well within the laminar limit.

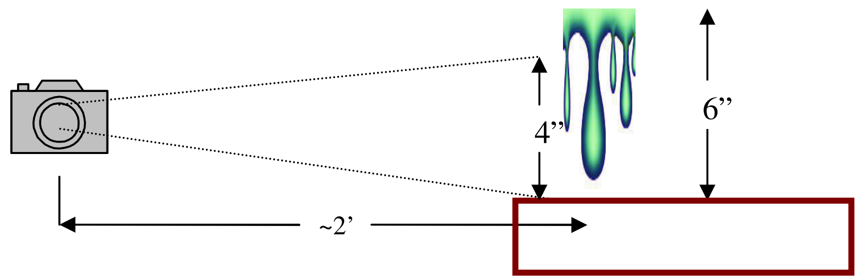

Figure 2: Schematic of the photographic set up.

Shear thickening fluids are a relatively rare phenomena which generally form when a sufficiently dense fluid reaches critical strain rates.[2] Adding cornstarch to water effectively increases the overall density of the liquid but maintains the general properties of a fluid. The high density mixture has relatively large particles which are not perfectly spherical. The result is flow that has elements that may orient themselves as a response to flow excitation. Thus, when a large change in velocity (acceleration) is experienced by the flow, particles begin to reorient in a fashion that increases the fluid density near the applied strain. If the particles reach a critical shear strain rate, the local sheared area begins to act more like glass and is capable of fracture. Once an applied shear is removed, the particles are able to relax back into their original orientations; the fluid flows more naturally and all signs of disturbance disappear. Thus, the viscosity of

[1]Calculating a Reynolds number for this flow was difficult because the viscosity is continuously changing and the density is dependant on the concentrations of water and cornstarch, which changes over time as water is more easily lost or transferred the more the fluid is subjected to a shear. [2]

the fluid is dictated by a balance between the relaxation time for particle orientations that promote fluid flow and an applied shear which forces ordered structure of particles. Quicksand is one example of a naturally occurring system with similar characteristics to a cornstarch/water mixture. The shear thickening response of quicksand explains why quick, forceful movements make the struggle to escape more difficult.[2]

The photographed flow was of a mixture of cornstarch and water (~55% cornstarch). The result is an opaque fluid that clearly marks the boundary of the fluid flow. The fluid was light using a low level of ambient lighting from dim, surrounding halogen lights. The flash from the camera provided the primary source of lighting.

The photograph was created using a Nikon D80, digital SLR body with an image resolution of 3872x2592 pixels. The field of view of the oozing fluid was 5" by 7.5" giving an approximate spatial resolution of 0.0013 in/pixel and the fluid was 2 feet from the lens. The lens focal length used was 135mm on a Nikon DX AF-S Nikkor 18-135mm 1:3.5-5.6G lens with a polarizing filter. The image was exposed at an f-stop of 5.6, a shutter speed of 1/60sec and an ISO speed rating of 200. The maximum velocity of the flow was roughly 8 in/s; therefore the flow moved 0.29 inches during the exposure, which is above the spatial resolution of the image; however the image is spatially resolved because the flash was used.

The photograph exposes the behavior of a shear thickening fluid. Some sections of the streaming fluid appear to hold shape during the travel down as deviation from the main flow is resisted by shear thickening. Furthermore, by looking at the regions were there are sharp velocity changes near the collision of the static fluid on the table, we see that the flow maintains a cylindrical shape for a few moments. Below this region, the fluid appears more like a liquid should, with a glassy, reflective surface and near uniform free surface. The main difficulty in photographing such a fluid is the necessity to capture a brief shear dependant event in a way that expresses the various states of the fluid. For this image, the fluid physics are shown relatively well, but require some explanation for a viewer to fully understand. A time series may have been a better method of communicating this information, however, the single still image had a greater appeal to me. I did have one time series that would have made a good time lapse, but I decided I liked the element of the unknown the single image produced. If I were to do future work with this fluid I would like to make a time lapse of the fluid being thrown against the ground and follow it until it reached a fully relaxed state. However, I feel that the best way to appreciate this fluid is to actually hold it in your hand; feeling the changing textures between liquid and near solid is the most interesting aspect of the flow.

References:

1. Munson, Bruce R., Donald F. Young, and Theodore H. Okiishi. Fundamentals of Fluid. 5th ed. Hoboken: John Wiley & Sons, Inc., 2006. 15-18.

2. Woodcock, Leslie V. "Origins of Shear Dilatancy and Shear Thickening Phenomena." Elsevier 111 (1984): 455-461. Inspec. Norlin Library, Boulder. 09 Dec. 2007.